Role of nuclear radii in the exotic cluster-decay

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Introduction

Recently, a renewed interest has emerged in nuclear physics research. This includes low energy fusion process, intermediate energy phenomena as well as cluster-decay and/or formation of super heavy nuclei [1]. In the last one decade, several theoretical models have been employed in the literature to estimate the half-life times of various exotic cluster decays of radioactive nuclei. In these models, one needs complete knowledge of the interaction potential as well as of nuclear radii. Our aim here is to study the effect of various nuclear radii forms available in the literature [2–8] on the cluster decay process.

The Model

In the spirit of proximity force theorem [9], the nuclear potential $V_N(R)$ of the two spherical nuclei, with radii C_1 and C_2 and whose centers are separated by a distance $R = s + C_1 + C_2$ is given by

$$V_N(R) = 2\pi \overline{R} \phi(s), \tag{1}$$

where

$$\phi(s) = \int \{H(\rho) - [H_1(\rho_1) + H_2(\rho_2)]\} \, dZ, \tag{2}$$

and

$$\overline{R} = \frac{C_1 C_2}{C_1 + C_2}, \tag{3}$$

with Süssmann central radii C_i given in terms of equivalent spherical radii R_i as:

$$C_i = R_i - bR_i^{-1}. \tag{4}$$

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Here surface diffuseness parameter $b = 1$ fm and nuclear radii R_i taken as given by various authors [2–8]. These different nuclear radii are labeled as R_{Prox77} [2], R_{AW} [3], R_{Prox00} [4], R_{Royer} [5], R_{Ngo} [6], R_{Bass} [7] and R_{CW} [8].

For the cluster decay calculations, we use the Preformed Cluster Model (PCM) based on the well known quantum mechanical fragmentation theory [1]. The decay constant λ or decay half-life $T_{1/2}$, is defined as:

$$\lambda = \frac{\ln 2}{T_{1/2}} = P_0 \nu_0 P, \tag{5}$$

where P_0, P and ν_0 refers to the preformation probability, the penetrability and assault frequency, respectively.

For decoupled hamiltonian, the Schrödinger equation in η-co-ordinates can be written as:

$$[-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}} \frac{\partial}{\partial \eta} \frac{1}{\sqrt{B_{\eta\eta}}} \frac{\partial}{\partial \eta} + V_R(\eta)]\psi(\eta) = E\psi(\eta). \tag{6}$$

Results and Discussion

We present here the cluster decay calculations of ^{56}Ni, when formed in heavy-ion collisions. Since ^{56}Ni has negative Q-value (or Q_{out}) and is stable against both fission and cluster decay processes. Since it has a negative Q_{out} having different values for various exit channels and hence would decay only when it is produced with sufficient compound nucleus excitation energy E_{CN}^* ($= E_{cm} + Q_{in}$), to compensate for negative Q_{out}, their total kinetic energy (TKE) and the total excitation energy (TXE) in the exit channel as:

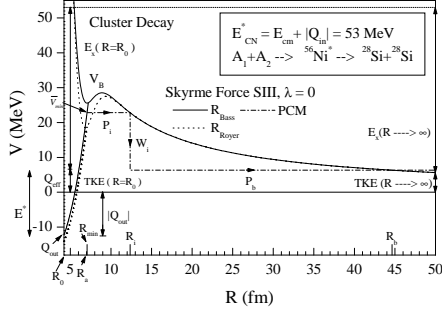$$E_{CN}^* = |Q_{out}| + TKE + TXE, \tag{7}$$

here fragments are considered to be spherical

FIG. 1: The scattering potential $V(R)$ (MeV) for cluster decay of ^{56}Ni* into ^{28}Si + ^{28}Si channel for different nuclear radii. The distribution of compound nucleus excitation energy E^*_{CN} at both the initial ($R = R_0$) and asymptotic ($R \to \infty$) stages and Q-values are shown. The decay path for PCM is also displayed.
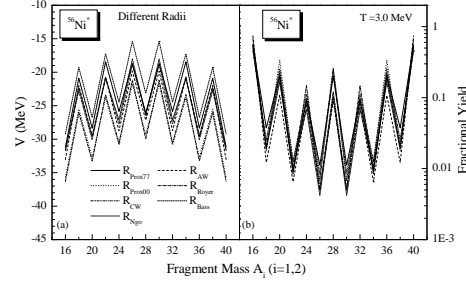

FIG. 2: (a) The fragmentation potential $V(\eta)$ and (b) calculated fractional mass distribution yield with different nuclear radii at $T = 3.0$ MeV.

so the deformation energy E_d is neglected (see Fig. 1). Here Q_{in} adds to the entrance channel kinetic energy E_{cm} of the incoming nuclei in their ground states.

Fig. 1 shows the characteristic scattering potential for the cluster decay of ^{56}Ni* into ^{28}Si + ^{28}Si channel for two different forms of nuclear radii (R_{Bass} & R_{Royer}). In the exit channel, for the compound nucleus to decay, the compound nucleus excitation energy E^*_{CN} goes in compensating the negative Q_{out}, the total excitation energy TXE and total kinetic energy TKE of the two outgoing fragments. The TKE plays the role of effective Q-value (Q_{eff}) in the cluster decay process. We plot the penetration path for PCM using Skyrme force SIII (without surface correction factor, $\lambda = 0$) with nuclear radius R_{Bass}. We begin the penetration path at $R_a = R_{min}$ with potential at this R_a-value as $V(R_a = R_{min}) = \overline{V}_{min}$ and ends at $R = R_b$, corresponding to $V(R = R_b) = Q_{eff}$. The Q_{eff} values are taken from ref. [1].

Fig. 2(a) and (b) shows the fragmentation potential $V(\eta)$ and fractional mass distribution yield at $R = R_{min}$ with $V(R_{min}) = \overline{V}_{min}$. The fractional yields are calculated within PCM at $T = 3.0$ MeV for ^{56}Ni* using various forms of nuclear radii. From figure, we observe that different radii gives ap-

proximately similar behavior, however, small changes in the fractional mass distribution yields are also observed. The fine structure is not at all disturbed for different radius values.

We have also calculated the half-lives (or decay constants) of ^{56}Ni* within PCM for clusters $\geq ^{16}$O. The variation in the cluster decay half-lives studied with respect to radius formula due to Royer (R_{Royer}) shows that the half-lives lie within $\pm 7\%$, excluding Bass radius formula where these lie within $\pm 10\%$ [10].

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